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METHODS FOR TECHNICAL DEVELOPMENT AND MODERNIZATION OF ELECTRICAL NETWORKS OF LARGE CITIES IN THE SOVIET UNION

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It is impossible to build economic and efficient electric power systems for large Soviet cities if 6-10 kilovolts is adopted as the highest voltage for feeder and distribution lines. Such a setup inevitably entails a great consumption of nonferrous metal and a complicated network of lines. And if the use of nonferrous metal in the municipal line is restricted, it will result in great losses of power and additional complications in the system.

An economically expedient scheme for a large municipal network can be obtained only by introducing "heavy" 35-110 kilovolt feeders. The number of 110 kilovolt feeders must be relatively small for the following reasons:

1. It is generally impracticable to use "heavy," i.e., high-tension feeders for overhead lines because of the impossibility of running 110-kilovolt lines in city streets. It is undesirable from an esthetic viewpoint and from the standpoint of the safety of the inhabitants. On the other hand, the use of cables for these 110-kilovolt feeders is very expensive. They cost about 15 rubles per kilometer for transmitting one kilovolt-ampere -- approximately 5 to 6 times more than for overhead lines.

2. The sharp rise in the cost of network equipment which would result from breaking up the 110-kilovolt (primary) substations into smaller 110-kilovolt units, makes it necessary to build high-capacity step-down substations. This in turn increases the cost of the 6-10 kilovolt feeders and complicates the system.

The next lowest voltage by the present scale of nominal voltages is 35 kilovolts. In our opinion, this is the voltage which must be utilized to develop and modernize the power networks of large cities in the Soviet Union. With a voltage of 35 kilovolts, cable lines may be used for the feeder network at a cost of approximately 4 rubles per kilometer per kilovolt-ampere. This is about one fourth the cost of 110-kilovolt cable lines.

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Specific loads kilowatts per square kilometer in large cities under reconstruction are increasing greatly because of the larger number of stories in buildings and the more extensive use of electric power. It is expected that specific loads will reach several thousand kilowatts per square kilometers. Each 20-30-story building requires 1,000 or more kilowatts. Supplying separate buildings and districts with such a high load-density by 6-10 kilovolt lines running from sources of supply several kilometers away cannot be considered advisable. Such supply would require supporting substations and, in this connection, 35/6--10 kilovolt substations are considerably cheaper than 110/6-10 kilovolt substations.

In a correctly-designed network for a large city, the introduction of 35-kilovolt feeder lines from stations located outside the city is combined with one additional step of voltage transformation. Network feeders from stations located inside the city require two stages of voltage transformation. Calculations have shown that the introduction of additional voltage transformation steps results in considerable power losses and consequently, increases operating costs.

Analysis of components of operating costs provides convincing proof that, on introducing a 35-kilovolt circuit in the network of a large city, the increase in operating costs is largely due to power losses in the transformers. However, this fact must not be allowed to stand in the way of introducing 35-kilovolt voltage into large city networks. The electrical industry must meet new and greater requirements with respect to the transformers it manufactures.

For a variety of reasons, our transformers have been designed for relatively great power losses. For example, a 10,000-kilovolt-ampere transformer with a 35 kilovolt high-voltage winding has a power loss of 1.2 percent at nominal load. Consequently, in selecting a transformer from a technical-economic standpoint, it is considered more profitable, due to the high losses, to install a transformer with greater power than required by the load. This is a clear indication of the abnormal state of transformer building. By using better types of steel and reducing the current density in the windings, it is now possible to obtain transformers with considerably lower power losses. Utilization of more efficient transformers would unquestionably result in other economies, and would facilitate extensive introduction of 35-kilovolt circuits in large city networks.

If for any reason, it is found inadvisable for factories to manufacture only transformers of higher efficiency, the problem of making them for municipal or industrial networks must be taken up separately, since considerable economies would thereby be effected. In rayon networks, power can be transmitted by overhead lines, but, as a rule, cable lines are necessary in cities and plants. There is little difference in the cost of overhead lines for 35 and 110 kilovolts; hence, the use of a "heavy" 110-kilovolt feeder in rayon networks can be defended from an economic viewpoint more readily than the decidedly less favorable use of this voltage in underground cables.

The electrical industry must solve the problem of producing at lower cost a reliable 35-kilovolt cable with a minimum strand cross-section.

Planning a 35-kilovolt line system presents certain serious problems. There are four possible variations in designing the low-voltage network:

1. A radial reserve network: each main operates on one supply source.

2. A loop (ring) network: the ends of each loop operate on one supply source.

3. A trunk network: the ends of each trunk feeder operate on different supply sources.

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4. A complex closed network: fed by several sources of supply.

A complex 35-kilovolt closed network is justifiable only when the 35-kilovolt network is well-developed, and if it is to be used for power exchange between the sources of supply.

The third type, the trunk network operating with closed trunk feeders, also is suitable only when these feeders must be used to exchange power between supply sources.

When it is necessary to use 35-kilovolt networks to exchange power between supply sources, the trunk network is preferable to the complex closed network because the latter is more complicated and expensive to operate.

In many large cities in the Soviet Union the supply sources are interconnected by means of 110-220 kilovolt lines which also serve to exchange power between the sources. In such cases, it is not advisable to erect 35-kilovolt networks for exchange of power between sources of supply.

The choice between the radial reserve system, the loop network, or the trunk network operated with open trunk lines, must take into account all local factors. The latter may require the erection of networks utilizing not one but two, or even three schemes. The relative merits and defects of the three schemes are too well-known to require mention here.

The problem of the most economical capacity for 35/6--10 kilovolt substations should be weighed carefully. Heretofore this problem, as it applies to electric networks in large cities, has not been studied sufficiently. In theory, the minimum capacity of a transformer substation may be equal to the power being distributed from the distribution points. In parts of a city where a 6-10 kilovolt supply network has been developed, replacing the distribution points with transformer substations cannot be considered economical. Moreover, such replacements would give rise to great difficulties during the construction and temporary operation of the line in the course of modernization. It is obvious that a better solution would be to supply several distribution points from transformer substations with substation capacity of 10,000-25,000 kilovolt-amperes. A 6-10 kilovolt network running from these substations would join the existing network carrying the same voltage, and would ensure the required reserve capacity for rapidly expanding loads. Such a network design would make it possible to avoid running supplementary heavy feeders from distant 6-10 kilovolt sources of supply.

The author does not deem it necessary to supplement the existing networks with 35/6-10 kilovolt lines in all city districts. In modernizing networks, it may prove economically advisable to retain 6-10 kilovolt feeders in individual parts of the city.

Whenever, in the course of modernizing a municipal network, it is decided to introduce a voltage of 35 kilovolts, great attention must be paid to the problem of eliminating 6-10 kilovolt feeders in newly developed districts of the city. When transformers with a higher degree of efficiency are used to meet the greatly augmented loads of large cities, complete replacement of distribution points by 35/6-10 kilovolt transformer substations may prove advisable. Consideration should also be given to the alternative methods of distributing power to network transformers at a 35-kilovolt voltage. This alternative would be profitable only if existing prices on 35-kilovolt cables and transformers were reduced, and if the cross sections of the 35-kilovolt cable strands did not exceed 50 square millimeters.

An excellent, economical solution of the problem of regulating the voltage for consumers is provided by replacing the distribution points by substations equipped with transformers which have automatic voltage regulation. Before any decision is reached on the economic advisability of modernizing networks by introducing 35-kilovolt feeders in any one of these variants, a study must be made of the expenditures involved in regulating consumer voltage. The lack of such a study might distort the technical-economic indexes in comparing various alternatives. It is obvious that it would be inadvisable to proceed with the modernization and development of such networks without taking special steps to regulate consumer voltage.

A good deal of modernization is needed on existing 6-10 kilovolt feeders. Even a very extensive loop system cannot be considered sufficiently reliable to guarantee the electricity supply for a large city. Failure in any one feeder causes a loss of the supply point, corresponding to a load of 2,000-5,000 kilowatts. The experience of the Soviet Union has shown that the modernization of large cities entails an increase in the number of stories in buildings and the use of electricity in apartments, etc., which, in turn, necessitates larger loads on the distribution points. Consequently, if a high-voltage feeder is damaged, a large load loss occurs.

The only satisfactory method of solving the problem of continuous consumer supply, when faults occur in the high-voltage feeder and distribution networks or in the transformers, is to construct a closed low-voltage network. In view of the impossibility of modernizing all sections of low-voltage networks in large cities to form closed networks, automatization of high-voltage feeders must be introduced more extensively. No complicated apparatus or installations are required. The Ministry of the Electrical Industry can and must set up serial production of suitable apparatus. The industry must pay serious attention to improving the quality of electrical apparatus, and to manufacturing the new, simplified apparatus needed to build up efficient networks in large cities.

It must be noted, however, that automatization of the high-voltage feeders is not a complete solution of the problem of uninterrupted supply to consumers. Faults in the transformers and 6-10 kilovolt distribution lines also will shut off the consumers' current.

It was inevitable that increased demands for reliable service in large cities should give rise to problems concerning the conversion from open low-voltage systems to closed ones. In closed low-voltage systems, disturbances in supply will occur only when faults develop in the low-voltage network, and even then the dead areas will be quite small. With a closed system, when a cable burns out at the fault point, it is often possible to maintain consumer supply after faults develop in the low-voltage network. Such networks reduce losses of power and capacity. This is particularly applicable in the case of networks which permit centralized switching of network transformers out of the circuit when the load drops.

We cannot accept as normal the very limited amount of work that has been done in the Soviet Union on introducing closed low-voltage systems. Scientific work on these networks and installation of experimental sections of closed networks in cities should be one of our most urgent tasks for the years just ahead. Special attention should be paid to closed systems by the power combines which control the networks of large cities undergoing reconstruction. In this connection, studies should be made of the grid-type closed networks already developed.

The introduction of closed low-voltage networks must be unremittingly pursued without regard for the "childhood diseases" inherent in any new type of network. Mention should be made here of a group of Leningrad scientific workers and engineers under the leadership of B. L. Ayzenberg, who have spent many years on "limited" closed low-voltage networks. However, networks of this type cannot be used widely in large cities.

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Mozenergo's unfinished experiment in employing closed low-voltage networks of the grid type in one section of the Moscow network had a negative rather than a positive effect. As a result, introduction of this more modern type of network into the electrical economy of Soviet cities has been delayed.

The greatest possible attention must be paid to the electric supply of high buildings. The old methods of installation could hardly be called satisfactory. Detailed studies must be made of methods of connecting networks in high buildings with the general municipal network.

One of the most important questions in national economy is that relating to the voltage in low-voltage networks. Convincing evidence has proved it advisable to use 220 volts for private consumers, and to reconstruct the old low-voltage networks and build new networks on a 380/220-volt base. It is obviously possible to agree with this arrangement if one has in mind a city with relatively small load densities, in which apartment heaters are used extensively.

The supply of electricity to large cities undergoing reconstruction and development is subject to different conditions. In the first place, such cities are supplied with gas and district steam heating facilities, which almost completely eliminates the need for electric heaters in living quarters.

If we consider the electricity supply of a large city simply from the viewpoint of capital expenditures in constructing the network, it will be obvious that some form of 380/220-volt network will always be more profitable than any other form of construction. However, if allowance is made for the fact that connecting incandescent lamps to a 220-volt line will require a 20-percent increase in power and capacity, it would be difficult in our opinion, to find any economic advantages in a 220-volt network for large cities. It will be sufficient here to call attention to one fact: in converting a one-kilowatt lamp load from 127 to 220 volts, an additional 0.2-kilowatt capacity is required at the power station. Computing the cost of one kilowatt of installed station capacity as 1,500-2,000 rubles, the additional outlay at the station will be 300-400 rubles. To this must be added the expenses connected with increasing the power of the network transformers, enlarging the cross sections of the high-voltage network, which must be determined in accordance with economical current density, etc. Moreover, it will take 25 percent more fuel to supply the lighting load than when 127-volt incandescent lamps are used. Connecting 220-volt lamps is equivalent to constructing a network with 20 percent larger power losses. There seems to be little reason for building a 220-volt network, and besides, it is more dangerous than one of 127 volts.

All the above-mentioned costs must be set off against the outlay of nonferrous metal in the low-voltage network only. In the large cities being reconstructed, the comparative length of low-voltage networks is less than in medium or small cities. The network transformers often supply indoor lines directly. The position of the late Professor V. M. Khrushchev on the advisability of connecting private consumers in large cities on a 127-volt circuit has never been refuted. However, in new districts the 220-volt network is quite feasible, since it appears reasonable to expect that in the next 10 years incandescent lamps will be entirely replaced by glow lamps.

The simplest measure to improve the voltage level in municipal networks is to set up installations which permit the introduction of independent voltage regulation in municipal and district networks. Transformers with provision for voltage regulation under load or auxiliary regulating transformers must be installed in district substations and power stations which have transformer connections with municipal and district networks. Networks in large cities are often rigidly connected to district networks.